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Address:
E.O. Paton Electric Welding Institute,
International Association «Welding»,
11, Bozhenko str., 03680, Kyiv, Ukraine
Tel.: (38044) 287 67 57
Fax: (38044) 528 04 86
E-mail: journal@paton.kiev.ua
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ESTIMATION OF GROWTH OF FATIGUE CRACKS IN LOAD-BEARING WELDED STRUCTURES AT RANDOM SPECTRUM OF CYCLIC LOADING

V.I. MAKHNENKO and **I.Yu. ROMANOVA**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

Considered is the procedure for estimation of growth of fatigue cracks in reinforcement of one-sided butt weld on a longitudinal beam of freight flat car at the preset range of random cyclic loading. It is shown that sequence of application of the loading spectrum elements has a substantial effect on the fatigue life of a structure. The use of the Monte-Carlo method in calculations allows generating probabilistic characteristics of failure related to random application of cyclic loading.

Keywords: *welded structures, freight flat car, fatigue crack, cyclic loading, Monte-Carlo method, probability of failure, amplification factor, estimation of fatigue life*

Many modern critical durable structures (constructions) experience the effect of alternating time-dependent loads, which are of a random character, the elements of spectra of these loads, i.e. their ranges and frequency, being well studied. However, the sequence of application of ranges of such time-dependent loads causes certain difficulties in estimation of the development of fatigue cracks because of its substantial non-linearity with regard to geometric sizes of a crack. Normally, the most conservative method is used in this case. With this method, elements of the loading spectrum are ranked in sequence, starting from the highest range of loads, and ending with the lowest one [1]. The extent of conservatism of such an approach at corresponding loading spectra may be much beyond the reasonable limits, i.e. lead to a high disagreement between the calculated and experimental results. In this connection, when choosing the sequence of ranking of the loading spectrum elements, noteworthy is the use of methods of the theory of random events [2], etc. This study is dedicated particularly to this issue.

The study considers a surface (semielliptical) crack (Figure 1), when its characteristic geometrical sizes c and a grow according to equation (1) per cycle $\Delta N = 1$ [1]:

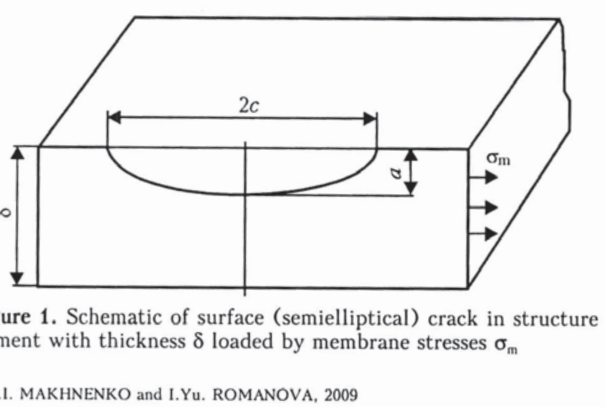

Figure 1. Schematic of surface (semielliptical) crack in structure element with thickness δ loaded by membrane stresses σ_m

$$\frac{dl}{dN} = C_0\Delta K_I^m(l), \text{ if } \Delta K_I^l > \Delta K_{th}(R) \ (l = a, c);$$
$$\frac{dl}{dN} = 0, \text{ if } \Delta K_I^l < \Delta K_{th}(R), \quad (1)$$

where ΔK_I^l is the range of variations in stress intensity factor $K_I(l)$, respectively, at apex of the crack with sizes c and a (see Figure 1):

$$\Delta K_I^l = K_I^{max}(l) - K_I^{min}(l); \quad (2)$$

$$R = K_I^{min}/K_I^{max}; \quad (3)$$

C_0 and m are the experimental characteristics of a material within the crack zone [1]; and $\Delta K_{th}(R)$ is the threshold value of $K_I(l)$ obtained experimentally [1].

The values of $K_I^{max}(l)$ and $K_I^{min}(l)$ are found from the known values given in [1] and from the other dependencies, allowing for sizes of cracks, l, and preset elements of loading spectrum, P_j (Figure 2), as well as non-relaxed residual stresses σ_{res} within the crack zone.

Numerical integration of equations (1) through (3) at the preset initial sizes of a crack, $l_0 = a_0$, c_0, allows finding $l(N)$ depending upon N up to critical sizes of the crack, l_{cr}, at which the period of its spontaneous growth takes place, which is determined by the following condition:

$$Y = -K_r + f(L_r) < 0, \quad (4)$$

where $K_r = \frac{K_I^{max}(l_l)}{K_{IC}}$; $L_r = \frac{\sigma_{ref}}{\sigma_y} \le L_r^{max} = \frac{\sigma_y + \sigma_t}{2\sigma_y}$; K_{IC} is the fracture toughness of the material in the crack zone; σ_y is the yield stress; σ_t is the tensile strength of the material in the crack zone; $\sigma_{ref} = \sigma_{ref}(l)$ are the stresses in the crack zone under load $P_j^{max}(N)$, which are responsible for the plastic instability mechanism [1].

It is assumed in (4) that $f(L_r) = 0$ at $L_r > L_r^{max}$, which corresponds to fracture by the plastic instability mechanism.

Dependence $f(L_r)$ at $L_r \le L_r^{max}$ is usually approximated by the following equation [1]: